Multibeam Mapping of the Uncertainty of the Seafloor in the Southern East China Sea

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LONG-TERM GOALS

The long-term goal of the Quantifying, Predicting and Exploiting (QPE) Uncertainty DRI is to understand and exploit (if possible) the fundamental acoustic, oceanographic, bathymetric and geoacoustic uncertainties of the tactical naval environment, and demonstrate how they may be exploited tactically or strategically in an Exercise Area. Focussing on the seabed, our goals are to understand the fundamental tactical and strategic uncertainty of the bathymetric and geoacoustic environment, and develop methods for their representation, visualization, computation and manipulation in a manner consistent with models of sonar performance estimation and prediction.

OBJECTIVES

The scientific objectives of the UNH team are:

1. Understand the sources and magnitudes of bathymetric and geoacoustic uncertainty in the Southern East China Sea Exercise Area, and their implications for acoustic modelling.
2. Develop a framework methodology for expression of user-relevant uncertainty in the bathymetric and geoacoustic context.
3. Develop appropriate representation/visualization techniques for the uncertainty models developed.
4. Provide continually updated “best available” estimates of bathymetry, backscatter and uncertainty models to the QPE technical group, consistent with data access limitations.

APPROACH

Bathymetry and geoacoustic (in this context referring to seeps, mud volcanoes and other non-bathymetric sources) uncertainty are primary drivers in the acoustic propagation problem, defining one of the complex boundary conditions for the ocean waveguide. The roles of the two components can often be complementary however, with bathymetry being very significant in areas of complex and steep relief, and geoacoustic uncertainty being significant in otherwise undistinguished bathymetric environments [Holland, 2006]. Both, however, are typically poorly sampled spatially and temporally

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in most tactical environments, although they can be well characterized, at least spatially, when sampling is done. Understanding the variability of the unobserved, therefore, is critical to characterizing and exploiting the uncertainties that are significant for the tactical environment.

We approach the problem of fundamental bathymetric uncertainty by considering not the best possible bathymetry, but the bathymetry more likely to be available in a tactical situation where the modeling uncertainty is likely to be dominant. The vast majority of the world is mapped, at least in shallower water, with at best sparse soundings from a single-beam echosounder, therefore it is unrealistic to believe that high-resolution maps are possible for most situations. We have previously approached this problem by taking modern high resolution multibeam echosounder (MBES) data and subsampling it to more typical data densities, with the intent of calibrating our estimates of bathymetric uncertainty from such data, and groundtruthing the *ab initio* estimate of uncertainty for our target area (using methods such as [Calder, 2006; Goff *et al*., 2006]). Limitations on availability and distribution of suitable MBES data, however, have made this approach problematic within the QPE effort. Here, therefore, we have chosen to focus on the data made available as part of the QPE field program, which is more dense (but less regular) than typical archive survey scale data, but not full coverage MBES data. We can assess the uncertainty of the source data against limited distribution MBES data, and then using only the generalized parameters of an uncertainty model fit to these estimates construct a continuous model of bathymetry and associated uncertainty. Iteration of this method allows us to check the calibration of the uncertainty models as well as providing guidance on bathymetric uncertainty in the region of interest. This scheme also allows us to determine the likely observability *in situ* of small, but potentially significant features (e.g., sand ridges [Liu *et al*., 2000]) that might be present in the region.

Information about important geoacoustic features, e.g., mud volcanoes or pock-marks [Yin *et al*., 2003] (which are often associated with the presence of gas in the sediment, and the effusion of gas into the watercolumn), is even less well defined. Although we might glean some information about their presence from backscatter measurements and watercolumn data in a specific case, we will likely never have sufficient information to fully characterize them deterministically. We hypothesize, however, that a stochastic description of their mean effect might be effective in an uncertainty-augmented acoustic propagation scheme. We are therefore developing suitable spatial statistical models [Cressie, 1993], based on the inferred acoustic groundtruth from backscatter, water column acoustic backscatter and other pilot and field-program observations, to allow for such incorporation, and the visualization and representation techniques to allow them to be fully exploited.

The sources for all of our research under this program are high-density bathymetric, acoustic backscatter and watercolumn observations; these data also proved essential for the planning and development of the field experiment. The opportunity for new data collection being limited, we based the dataset on public and government databases, and have continued to add new data as observations are made available from the pilot and field experiments. Coarse bathymetric products suitable for public release have been made as required and published on the QPE website, and specialized products are made on request; we continue to maintain a geospatial database for the data, including visualization products. Current limitations on distribution of data from some sources mandate that high-resolution bathymetric and backscatter products cannot be publicly distributed. These data are maintained separately, and products are released only as required (to qualified recipients).

WORK COMPLETED

Database Assembly and Product Creation: We have taken data made available from the QPE field program, including Kongsberg EK500 single-beam water-column data from the Taiwanese OR1, OR2 and OR3 and limited Kongsberg EM122 MBES data from the R/V *Roger Revelle*, and processed the data for use by other participants in the DRI as well as for our own research. These data have been converted from a number of different (occasionally custom and incompatible) file formats into conventional data processing packages using specifically developed software, processed, and output in a variety of data formats suitable for further data processing (e.g., MATLAB objects), databasing (e.g., ESRI ArcGrid objects) and visualization (e.g., Fledermaus SD objects). Standard plain-text ASCII objects are always maintained as a 'lowest common denominator' method of making the data widely available. This year, advances in data visualization software have also allowed us to make the watercolumn imagery from the EK500 available in a specialist tool for annotation, visualisation and analysis. This provides another avenue for exploration of the connections between the in-water acoustic signals observed and their mean effect on the ocean waveguide. The bathymetric data from the EK500 show a great deal of variability due to mis-detections in the watercolumn, and the effort to make them ready for public consumption will continue for a short while in the next reporting period. Preliminary products from other sources have been made available for the general QPE community, and more refined products (e.g., at higher resolution for MBES-derived bathymetry) will follow .

Bathymetric Uncertainty Calibration: We have estimated the uncertainty of the field program's MBES-derived bathymetry as an adjunct to our prior estimates of bathymetric uncertainty in the field program area. Data distribution limitations preclude merging the current data with the prior databases, but the field program's uncertainty is comparable with the uncertainty in the Limited Distribution data with mean shifts per depth estimate well within the expected uncertainty bounds. We have also continued our examination of the uncertainty of field-level source data (rather than best available high resolution data) by conducting a comparison between the EK500-derived depths and the MBES-derived bathymetry where available.

Unobserved Geoacoustic Uncertainty: We have continued to utilize the pilot and field program data from the EK500 echosounders on the OR1, OR2 and OR3 in order to quantify the potential for geoacoustic phenomena (such as seeps, mud vocanoes, etc.) within the target area that might have significant effect on the ocean waveguide. Work on this topic has been limited in the past by data distribution constraints; newly available data from the field program, however, allows for repeated observations in the same area at different times, and dense observations in some areas within short periods of time. We have extracted, processed and georeferenced this data, so that it may be used in the next reporting period for analysis and potential modeling of the uncertainty of the unobserved.

RESULTS

Medium resolution (50m) estimates of the depth and uncertainty of the field program MBES-derived bathymetry are shown in Figure 1. Compared with alternative but limited distribution high resolution sources, the mean depth difference is 2.08m, with standard deviation of 5.64m. The difference distribution is heavily leptokurtic (kurtosis 16.81) but symmetric (skewness -6.3×10^{-5}) with 95% Highest Density Region (HDR) on [-14.88, 8.99] m. The bias is well within the expected uncertainty, and the estimated uncertainty of the surface is within 1% of depth everywhere with (one sided) 95% HDR at 0.45% depth, indicating a high-accuracy estimate of depth. The uncertainty is not uniformly distributed, however, with higher uncertainty along the canyon walls and other areas of higher slope.

This is typically the case with estimates of this type due to the translation between horizontal and vertical uncertainty in the presence of slope, but may have significant implications for acoustic signals traversing the canyon structures in the region. Comparison of the EK500-derived depth measurements against the best available estimates of depth show a bias of 1.07m with a standard deviation of 1.38m, although the distribution is leptokurtic and mildly skewed with 95% HDR on [-0.64, 4.54]m. A mean bias of this kind could be readily explained by use of a simple, fixed sound speed correction in the single-beam echosounder, especially in the oceanographic environment of the exercise area.

Examples of the midwater acoustic backscatter data from the EK500 echosounder are shown in Figure 2–5, illustrating the utility of this type of information and the benefit of an integrated visualization environment. Figure 2 shows an example of a tall backscatter anomaly on the shelf-edge (at approximately 125m depth) at the head of the southwest branch of the North Mien-Hua Canyon, possibly associated with a seabed seep of some kind. It is difficult to determine the actual cause of the backscatter anomaly from a single observation of such data, but use of multiple spatio-temporally referenced observations in a consistent visualization environment may allow for sufficient confidence to be built up to impute a cause in some cases. Figure 2 also illustrates the interactive environment in which the data was manipulated and processed. This environment provides for fast access to the data, maintenance of spatio-temporal referencing, and easy modification of the visualization properties such as colormaps, zoom scale and other rendering effects. Our experience has been that access to a system of this type significantly improves the rate of discovery in midwater data such as examined here, particularly in flexibility to improve rendering of the data interactively in order to highlight features of interest.

Figure 3 captures what may be an active oceanographic event passing relative to the transducer as it moves through the water, reflected in the variability of the acoustic backscatter of the surface layer of water. (This section is located further northeast on the shelf relative to Figure 2, in approximately 135m of water.) Geospatially, this data is wrapped in a small area about 25° 42’N, 122° 37’E, Figure 4, and shows the transient event develop over the period of approximately an hour. While there are more direct methods to measure such effects, should appropriate sensors be in place at the right time, the ability to recover this information from a mobile sensor – and particularly one that can react in real-time to a developing event – can be a significant benefit.

Figure 5 illustrates the complexity in the watercolumn acoustic backscatter response that can be preserved in this type of data. Again, although an absolute classification of the cause of the observation is impossible from this data alone, the proximity of the effect to the seafloor at source, and the behaviour of the anomaly towards the left of the image (southwest and onshore from the Mien-Hua Canyon head) seems to suggest that this may be a natural seabed-related phenomenon.

One potential approach to the problem of identifying the probable cause of observed acoustic backscatter anomalies is to examine the same area multiple times. Typically this is rarely possible due to resource constraints, but observations-of-opportunity are possible in the case of the field program data due to the pattern of observations required by the other experiments that were conducted (Figure 6). Here, only those tracklines for which acoustic backscatter imagery is available are shown, but it is clear that there are multiple opportunities to examine coincident tracks at multiple depths and in multiple orientations with respect to the shelf edge at periods between a few days and a month. The opportunity to correlate any observed anomalies may provide the means to separate episodic from persistent sources and therefore approach a classification, a preliminary step in determining a model of geoacoustic variability that might be extrapolated to the remainder of the area of interest.

IMPACT/APPLICATIONS

Availability of high-resolution bathymetric uncertainty estimates provides for appropriate interpretation of the available database when used in context for either planning or analysis of acoustic, oceanographic or geoacoustic observations. Integration of watercolumn observations within a single, consistent georeferenced framework allows for coherent contextual analysis, potentially improving insight into the causes of observed penomena. Watercolumn data may also provide useful background information, especially when repeated observations-of-opportunity are available in a consistent environment for visualisation, to interpret the causes of observed acoustically significant effects in the ocean waveguide that may be geographically or temporally coherent. They may also be useful for cross-calibrating backscatter measurements and derived products, and investigating the (stochastic) potential for active geoacoustic features.

RELATED PROJECTS

None

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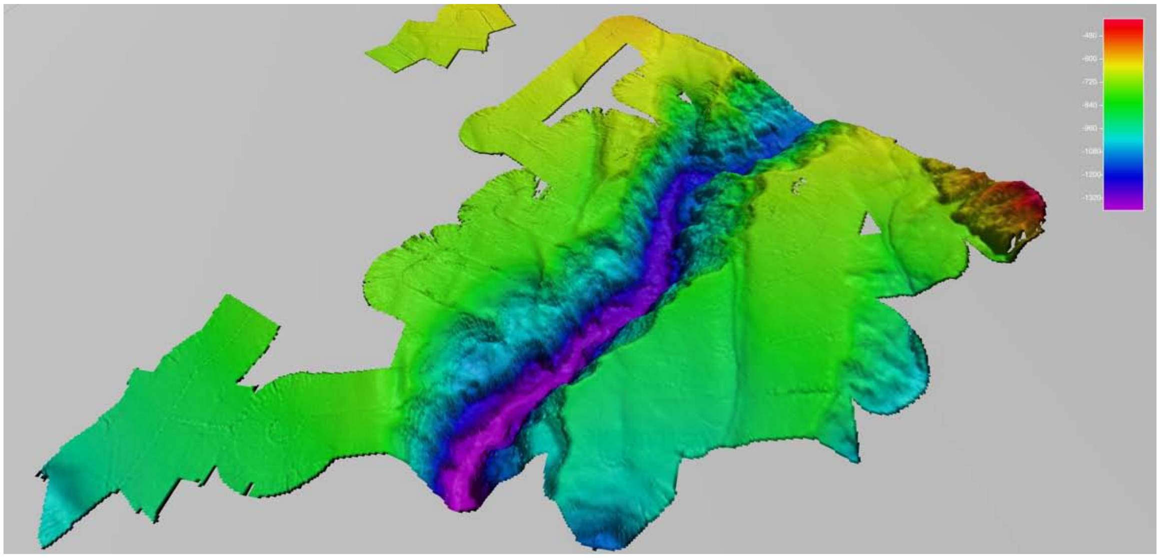
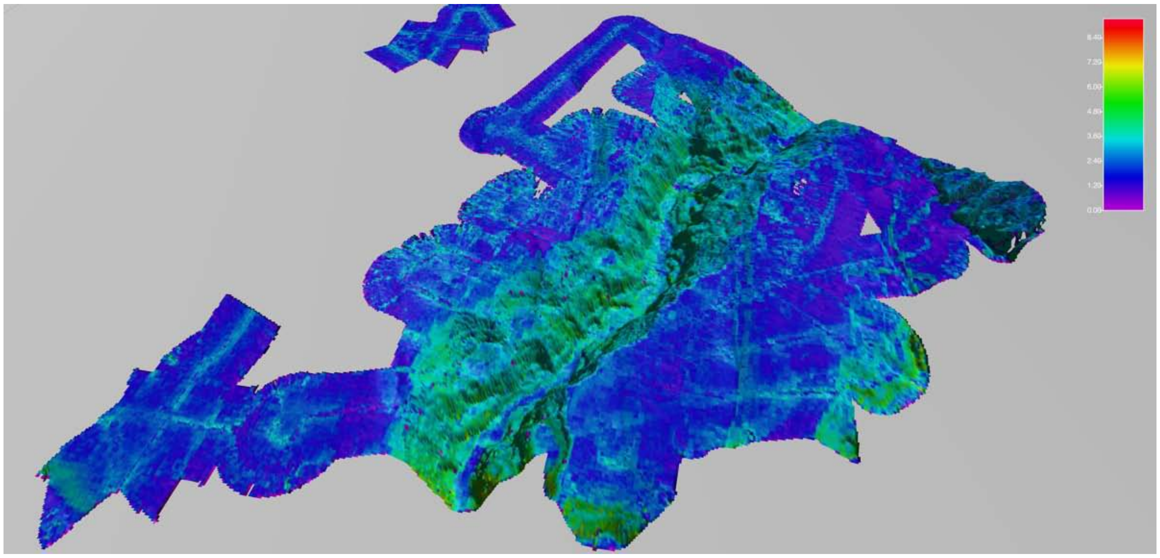
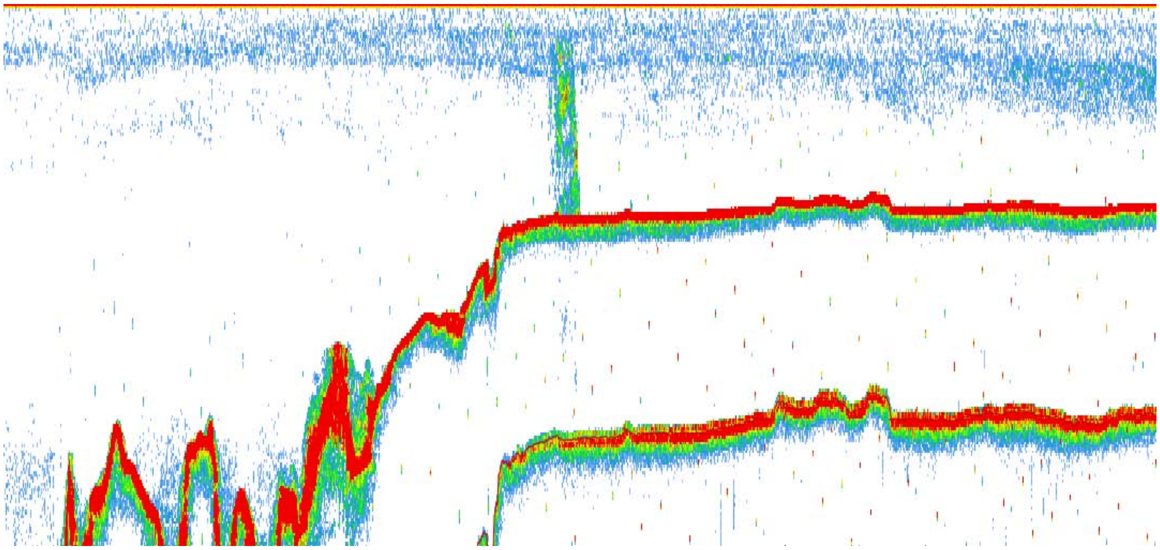


a) Estimated bathymetry from the field program observations. Depths range from 392m to 1384m, representing depths in the southwest-most branch of the North Mien-Hua Canyon system. [Depths extend to 1384m in the deepest part of the canyon mapped, but are generally 700-800m in the majority of the area mapped.]

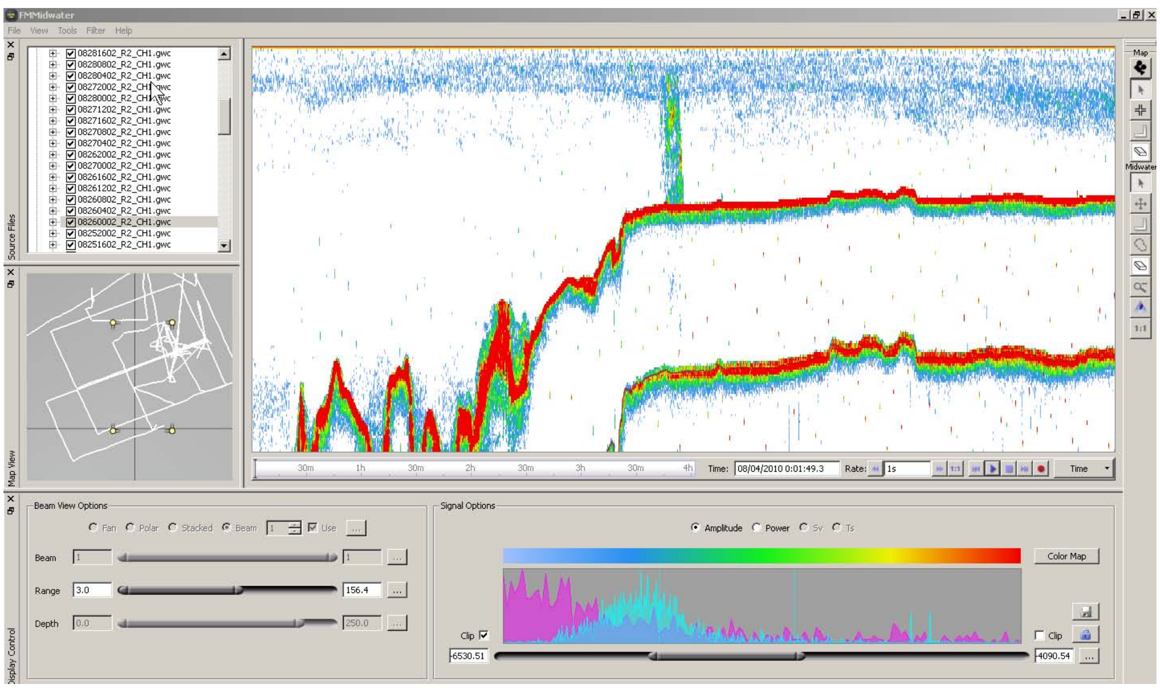


(b) Bathymetric uncertainty estimate corresponding to depths in (a), color-coded over the bathymetry. Uncertainties range up to 9.3m (1σ), or approximately 1% of depth although 95% of the estimates are under 0.45% of depth. Higher uncertainties are associated with steeper sloped areas such as the canyon edges.

Figure 1: Bathymetric depth and associated uncertainty estimated from the Kongsberg EM122 Multibeam Echosounder on the R/V Roger Revelle during the QPE Field Program (Cruise ID RR0908). The data shows self-consistency on the order of 0.45% of depth, and comparison with other, independent, sources show a difference with standard deviation of 5.6m (~0.6% of mean depth in the area).



(a) Possible ground seep on the canyon edge in the southwest-most branch of the North Mien-Hua canyon system. [Image showing acoustic backscatter immediately below the echosounder, with relative backscatter levels manipulated to show detail of the possible seep.]



(b) Example of GUI interface of the IVS MidWater tool, developed in conjunction with CCOM/JHC. This tool provides for very rapid access to large amounts of data, easy manipulation of the visualization parameters such as colormaps, spatial area being shown, and time range of the data considered. Data timestamping and georeferencing is maintained throughout.

Figure 2: Example of processed acoustic backscatter below the R/V Ocean Researcher 1 on 2009-08-24, showing a possible ground seep event. Positive identification of the causes of such signals is difficult, but may be possible with repeated measurements of this type.

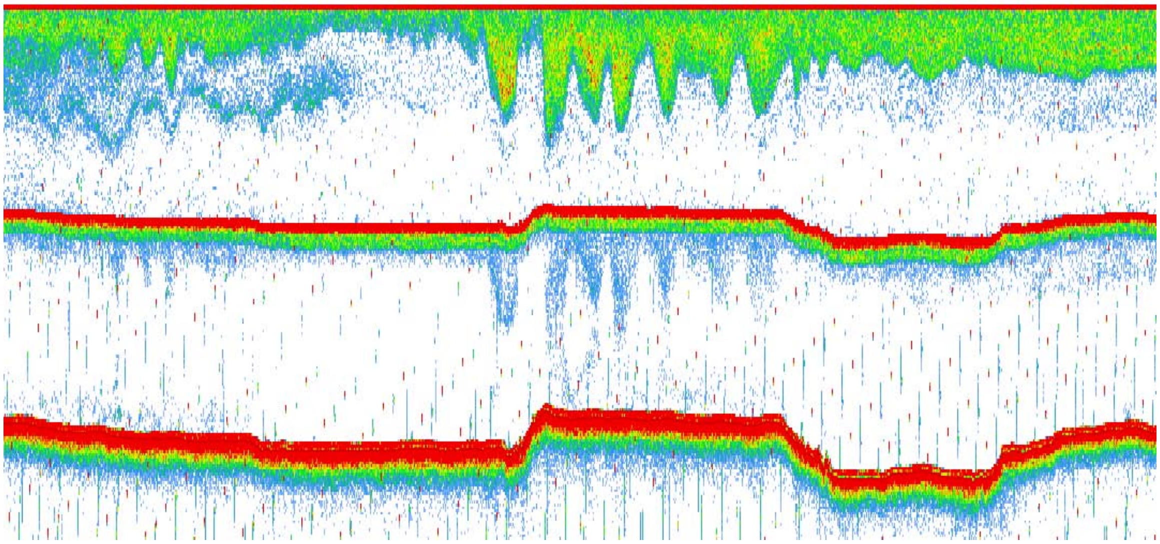


Figure 3: Example of active oceanographic events reflected in the acoustic backscatter recorded by the Kongsberg EK500 echosounder, in this case significant horizontal variability in the surface layer on the shelf over a period of approximately an hour. [Color-coded acoustic backscatter in a vertical slice below the ship showing surface variability, the first return and the second (surface) return]

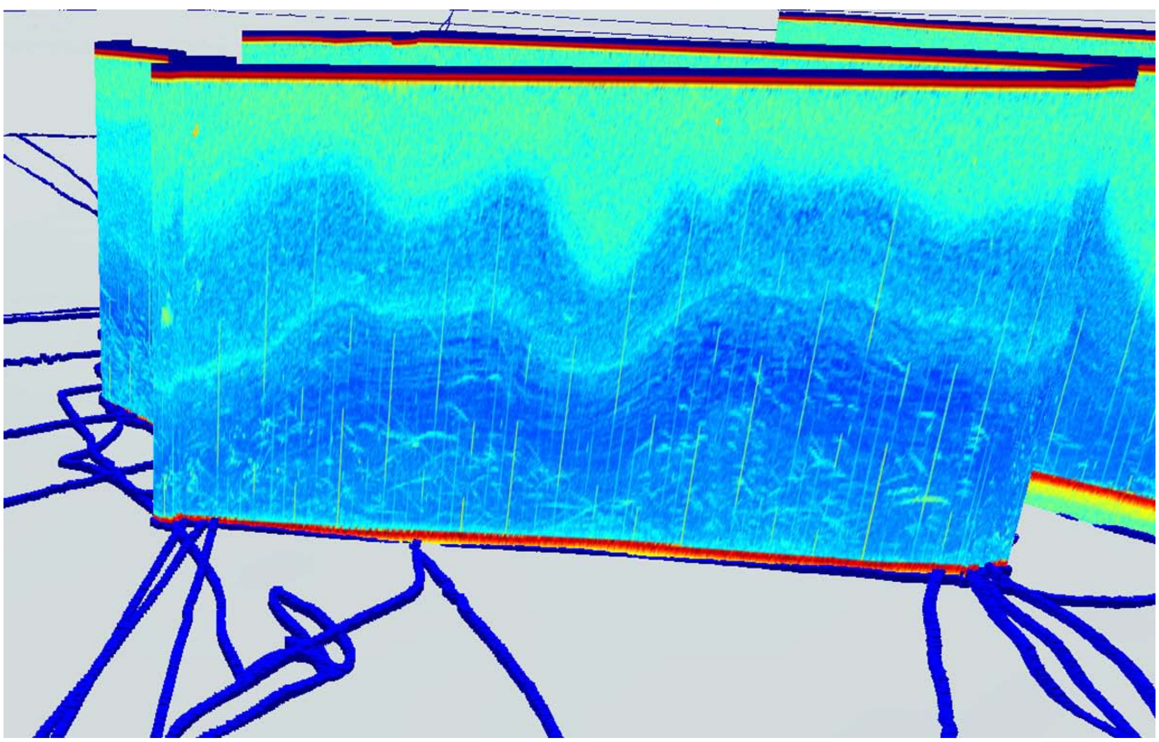


Figure 4: Representation of the vertical profile acoustic backscatter data of Figure 3 in an interactive 3D visualization environment, showing a transient oceanographic event pass under the R/V Ocean Researcher 1. The watercolumn data is represented as a color-coded curtain in the appropriate location, while the derived depths from the same cruise are shown as blue cubes. Examination of the time history of this data can allow the event to be studied as it evolves over a period of approximately an hour.

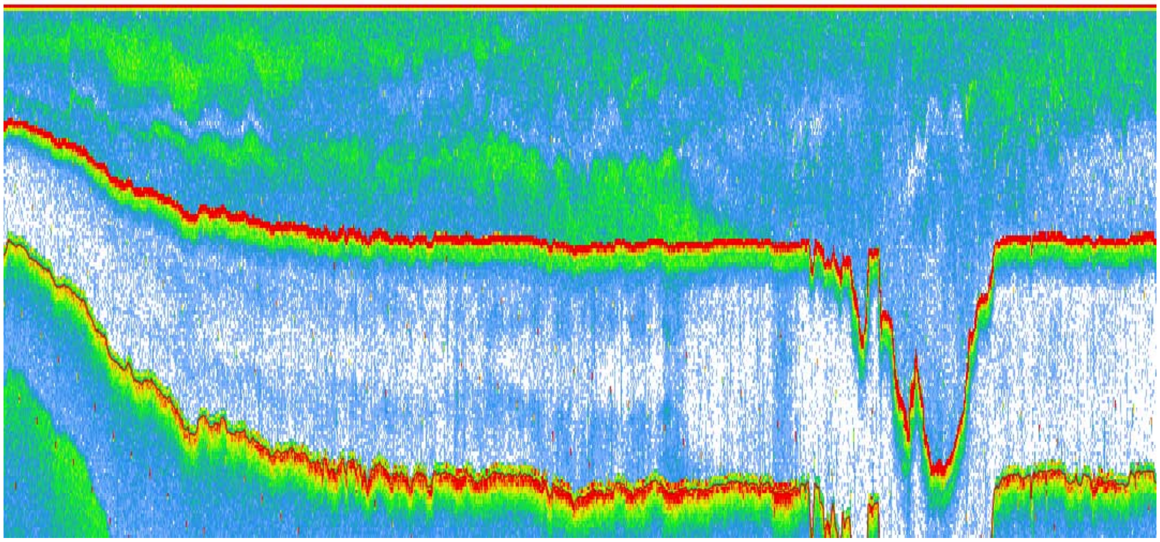


Figure 5: Example of stratification within the watercolumn acoustic backscatter, and a bottom-following reflector, possibly being shaped or directed by the oceanographic environment. [Color-coded acoustic backscatter in a vertical slice below the ship showing horizontal stratification and a stronger reflector close to the first acoustic return in close spatial proximity to a canyon head.]

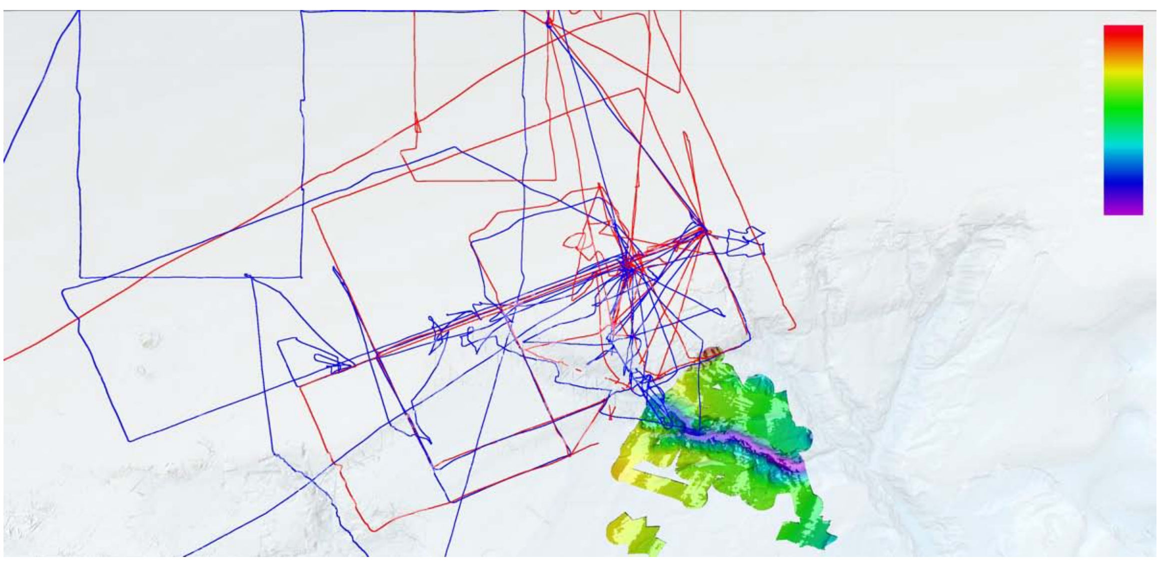


Figure 6: Location of field program cruises which have acoustic backscatter measurements in the watercolumn. Coincidence of many of the tracklines allows for multiple observations of the water mass in the same area at different times, thereby providing the potential to identify the cause of any phenomena, and possibly provide information for models of phenomenon density in the area.